MARCH, 1919
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ELECTRICAL EXPERIMENTER

SCIENCE AND INVENTION

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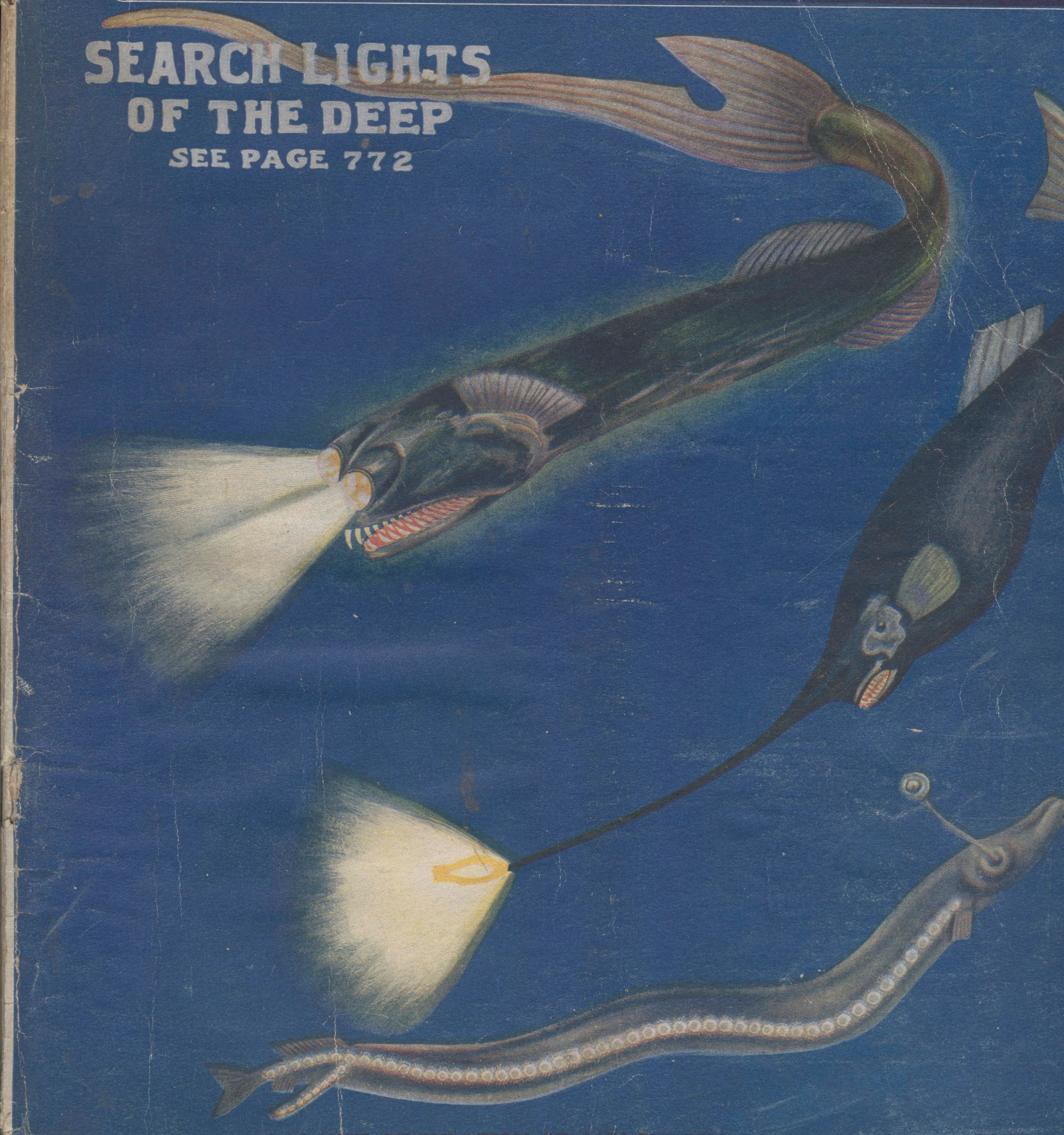
SEARCH LIGHTS OF THE DEEP

SEE PAGE 772

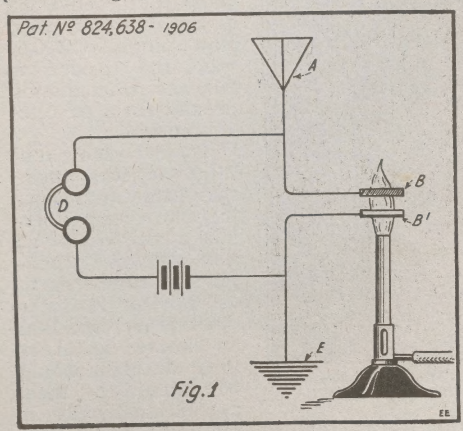


How I Invented the Audion

By Dr. LEE de FOREST

Written exclusively for the Electrical Experimenter

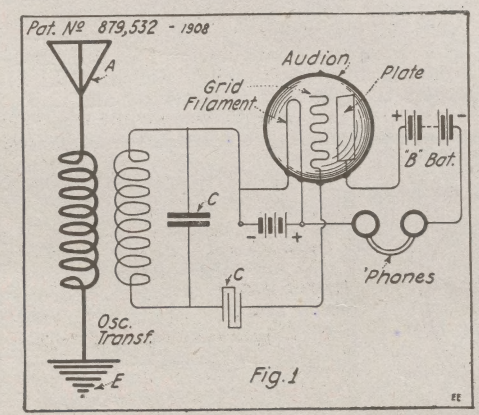
THE first conception of a detector of Hertzian waves which should employ the medium of heated electrodes or heated gas came to me as follows: In the summer of 1900 I was experimenting on a new type of electrolytic



The First State in the Development of the Audion by Dr. Lee de Forest. The Aerial and Ground Were Connected to Two Electrodes Placed in the Flame of a Bunsen Burner, with Successful Results.

detector, doing this work at night in my room in Chicago. The receiving apparatus was placed on a table beneath a Welsbach gas burner. A spark coil which I was using as my source of oscillations was located in a closet about ten feet distant. One night I noticed that whenever I closed the switch of the spark coil by means of a string running across the floor from my table to the coil, there was a decided change in the illumination from the Welsbach burner. The light from the gas mantel increased very perceptibly and resumed its normal low brilliance as soon as the sparking ceased. This phenomena continued and imprest itself strongly upon my attention. My first thought was that I had discovered a new form of detector of Hertzian waves, of extraordinary sensitiveness, and was, naturally, much enthused, as any young investigator would have been under similar circumstances. But upon closer investigation of this novel phenomena I found that when the door of the closet was closed, or almost closed, the effect of the spark upon the gas burner ceased! This proved conclusively that I was dealing with sound waves coming upon a sensitive flame and not with electrical waves.

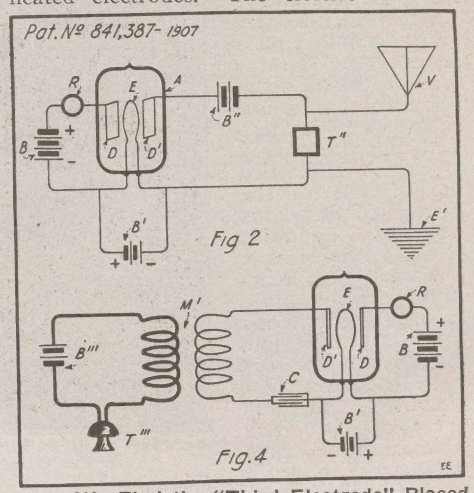
The delusion lasted, however, long enough to force upon my mind the conviction that heated gas molecules were sensitive to high frequency electrical operations, and I determined to investigate further at my first opportunity and actually discover evidence to substantiate my theory. I was unable to do this until the fall of 1902 or '03 when I returned to my gas mantel experiment. I first attempted to investigate the new detector phenomena by using two needles of steel, or platinum, placed close together in the incandescent Welsbach mantel. These



Later the "Third Electrode" Resolved Itself Into a Grid, Which Was Placed Between the Wing and Filament, Where It Could Act with the Highest Efficiency. In This Form It Has remained Practically the Same to the Present Time.

two needles were connected to a dry battery and telephone receiver. I was, however, unable to obtain any appreciable current between the two electrodes in the mantel. I then investigated the flame of a Bunsen burner and soon found a point in the outside envelope of the flame where an appreciable current did pass between the two electrodes, making a soft fluttering sound in the telephone receiver. (See Fig. 1, Patent No. 824,638, issued in 1906.) Then, connecting one electrode to an antenna and the other to the earth, I heard for the *first* time signals in the telephone receiver; signals which represented clearly the sound of the transmitting spark. Here at last was actually demonstrated my earnest belief in the existence of this new detector principle. My next step was to enrich the gas flame by putting a lump of potassium or sodium salt in the flame directly below the two platinum electrodes. This increased ionization caused increased flow of battery current, and a corresponding increase in sensitiveness of the new detector. I did considerable work then with various types of Bunsen burner arrangements for permanently enriching the gas flame, etc., and set up a laboratory type of flame detector which was actually used in 1903 for receiving signals from ships down the Harbor of New York.

The inconvenience of supplying a source of gas for the new detector was, of course, obvious, and I sought for other means of obtaining the necessary heated gas and heated electrodes. The electric arc first



Here We Find the "Third Electrode" Placed Inside the Bulb, Where It Logically Belonged, as Dr. de Forest Points Out. Fig. 4 Shows the First Use of the "Stopping" Condenser.

suggested itself. I anticipated that while this arc would be a detector, it would be exceedingly irregular and noisy in the telephone receiver. This was found to be the fact. The battery fed the arc thru the primary of the transformer, in the secondary of which was connected the telephone receiver, and, altho at times the looked for response to electric waves was thus obtained, the noise in the telephone receiver from the arc was so deafening that the idea was abandoned.

The next plan which suggested itself to me was to use incandescent filaments in an enclosed chamber. This arrangement as well as the gas detector, was illustrated in my patent No. 979,275, which bears the first date of November 4, 1904. This patent ap-

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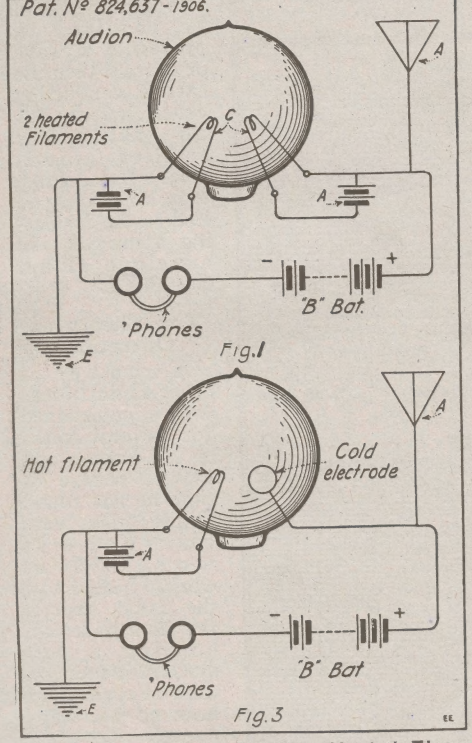
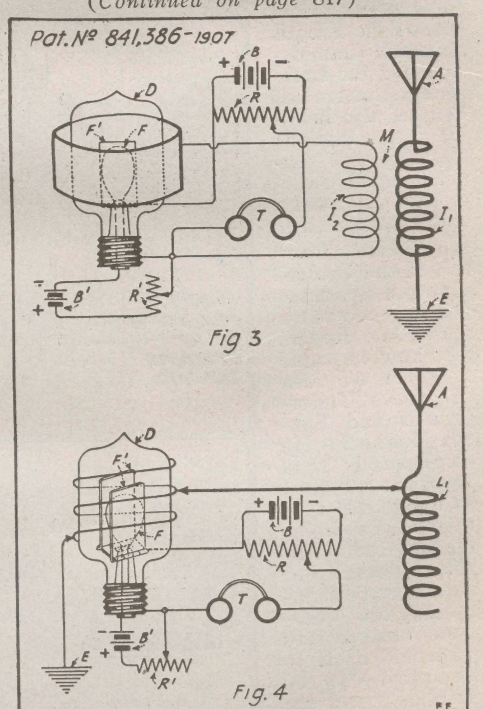


Here the Placing of the Two Heated Electrodes in a Vacuum Bulb Is Carried Out, as Well as the Final Adoption of the Cold "Wing." This Device Works Equally Well with Both Electrodes Hot, Thus Disproving Any "Rectification" Theory.



The First "Three Electrode" Audion Had a Piece of Tinfoil Wrapt Around the Outside of the Bulb—a Principle Frequently "Rediscovered," as Was the de Forest Electromagnetic or Coil Electrode, Fig. 4.

Gigantic 1,400 K.W. Radio Station at Lyons, France

(*Continued from page* 791)

work, it having been found readily possible to synchronize two such high-speed radio-frequency alternators at the works of the General Electric Company, some years ago.

North of the main antenna switch platform at the center of the station, there is a French design of static frequency multiplying system rated at 150 K.W. This set operates on the principle of the transformer frequency-changing principle, as developed by Joly and Arco.

Next we come to the western wing of the station, and here there are two of the largest arc oscillation generators ever built. They were designed by Mr. C. F. Elwell, formerly chief engineer of the Federal Telegraph Company of San Francisco, Cal., who first developed the Poulsen arc system to large powers, and each of these gigantic arcs are rated at 250 K.W. Either of these arc generators may be connected to the antenna thru the central antenna switch-gear, the lead wire running to the arc sets terminating in a massive single-pole, double-throw change-over switch, about five feet in length, which permits the instant connection of either set to the antenna.

Either of these powerful arc sets can be operated from the 300-K.W., 750-volt, direct-current motor-generator set, shown in the plan view and situated just west of the arc apparatus itself. This motor-generator comprises a three-phase alternating-current motor, direct-connected to a 750-volt, direct-current, 300-K.W. generator, which supplies the necessary high voltage direct current for operating the arcs. Dr. de Forest states that in his opinion, these large arc generators represent one of the very finest developments in radio transmitters that have yet been conceived and perfected. They have a distinct advantage over radio frequency alternators in that quick changes in wave length or frequency can be rapidly obtained, merely by changing the inductance and capacity in the oscillatory circuits connected to the arc itself. The radio frequency alternator is very reliable, and develops its full power in a very constant and reliable manner, but it is difficult, at least with the present design of this machine, to obtain with speed and efficiency a considerable change in the range of wave lengths and frequency, yet as Dr. de Forest has intimated, they are very efficient and desirable where the proper operating conditions are available, such as where but one or two wave lengths only are desired. The arc generator, on the other hand, is very simple and rugged in design, and requires but very little attention, even when operated over twenty-four-hour non-stop periods, which is often the case nowadays at many of the Government stations which are using arc sets, and many of which are in very successful operation in some of the largest stations of the United States as well as in Europe at the present time.

All of the transmitters at the Lyons station operate on long wave lengths, as the reader will perceive from the antenna frequency values given above, and the undamped wave system is used in all except the spark sets. The receiving apparatus is very elaborate, and has been installed in sound-proof receiving rooms, so as to realize the very highest efficiency in the receipt of long distance signals. The French radio engineers are using nothing but three electrode audions in all of their work, and one of their bulbs will be illustrated and described in the April issue. The French receiving sets make use of two or more amplifier bulbs, and when necessary a six-stage amplifier is used, which boosts the strength of signal received 1,000,000 times. Some of the clever work accomplished by the French Army and Navy radio experts during the war, with these powerful audion amplifiers can readily be imagined, and it is a matter of record that many valuable radio as well as regular telephonic and telegraphic wire messages of the Germans were tapt by French stations equipt with these powerful amplifiers.

The power for the Lyons radio station is transmitted for a long distance from a hydro-electric plant. The receiving apparatus was built by the Compagnie Generale Radiotelegraphique, whose shops are near Paris. The detector is, of course, the French type of audion. They employ a six-step audion amplifier, using the same standard type of bulb both for detecting and amplifying.

The ground connection of the station consists of a large number of copper wires radiating from the station and buried about two meters (6½ feet) below the surface of the earth. Many of these wires terminate in copper plates.

HOW I INVENTED THE AUDION.

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plication was not filed until the following February. The drawings, Figs. 2 and 6, of this patent show the incandescent or glow members both in the air, and sealed within a closed chamber.

It will be noted now that I approached the general problem of this new type of detector from an entirely different angle from that commonly supposed to-day. In the first place I always employed a battery, and this original battery was what is now universally called the "B battery." My source of electric current for heating purposes was second, and secondary, so that the vociferous contention of the advocates of the Fleming valve that the audion evolved from the Fleming valve, and was originally the Fleming valve with the "B battery" added as an afterthought, is entirely untrue.

It was now a very obvious development of the evolution thus far described, to partially exhaust the glass envelope containing the two incandescent electrodes, or filaments, so as to increase the conductivity of the space between them.

But Fig. 5 of this patent, showing the inclosed filament in a vacuum bulb, is interesting from another consideration because it contains the *first embryonic germ* of the later "grid" or *third electrode*. It was realized from the very first that a certain proportion of the high frequency energy from the antenna could be lost thru the bypath circuit supplied by the battery and telephone receiver. In order to prevent this the arrangement shown in Fig. 5 was tried out, wherein the local and high frequency circuits are kept separate. In this arrangement, as actually tried in the gas flame, no actual advantage was observed, because the high frequency electrodes were necessarily some slight distance from the path conducting the direct current, and hence the effect of the high frequency currents upon the ions carrying the local current was weakened.

During the years of 1904 and '05 my duties kept me almost continually away from my laboratory, in travelling about the country directing the installation of numerous radio stations; consequently there was little opportunity for prosecuting this development work, and carrying out the designs and sketches which I made from time to time. In fact, it was not until 1905 that a lamp manufacturer was found to undertake the construction of the various experimental forms of lamps which I had designed as a successor to the flame or arc detector. I was familiar in 1905 with Prof. Fleming's work on the subject of the "Edi-

son Effect" as utilized for the rectification of high frequency oscillations, or currents. This was interesting to me only as an evidence of growing activity along lines similar to those of my new detector. I was familiar, of course, with the phenomena originally discovered by Edison, and investigated and developed by Howell, Fleming, Wehnelt, et al; but from the very first of my work with radio detectors I always had in mind a *relay*, in the true sense of the word, *not a rectifier;* in other words, a detector in which the energy of the audible signal was supplied from a local battery. This local energy being merely controlled or released by the incoming signal. It had always been obvious to me that such a device should be more efficient than any form of rectifier where the signal indication is effected *only* by the energy actually received thru the antenna.

Fig. 1, Patent No. 824,637, is an obviously practical development of Fig. 5 of my first patent, No. 979,275. In this figure two incandescent filaments are sealed in the glass bulb, and each lighted from its own "A" battery. Here, as always, the original separate "B" battery is shown.

This figure is interesting to many, who until recently, if even now, have never heard that an audion of this type works equally well whether both electrodes are incandescent, or whether one is incandescent and the other cold. It might be well to point out now in this connection that during the patent trial—the Fleming valve vs. the Audion—a demonstration was made before the court where all three electrodes were in the form of filaments, where each could be heated to incandescence by a separate battery. The demonstration showed that when this device was connected up as an audion that either outside filament could be used as the "plate" electrode indifferently, and the signals were of the same intensity whether two electrodes were cold or all three hot. The purpose of this test was to demonstrate beyond all cavil the falseness of the assumption that *rectification* plays in any way an important or essential part in the operation of the three electrode audion.

Fig. 3 of the above mentioned patent No. 824,637 shows the next obvious step in the evolution of the audion i.e., doing away with the unnecessary battery for heating one of the electrodes. It was obvious, of course, that so long as the "B" battery was properly connected so that its positive pole led to the cold electrode, there was no necessity or advantage in heating this second electrode. The audion in this form—one hot and one cold electrode, and the "B" battery connected with this positive terminal to the cold electrode, was used for some months, and shows a sensitiveness as a detector, superior to that of the electrolytic detector, and far superior to that of the Fleming valve rectifier. We had, thanks to the "B" battery which was invariably employed, a genuine *relay* or *trigger action* of the high frequency oscillations upon the normal current-carrying ions, or electrons, passing between the two electrodes.

As everyone familiar with incandescent lamp or X-ray bulb phenomena knows, the proportions of current passing between two electrodes therein (one or both being hot) carried by ions or carried by thermions, depends chiefly upon the degree of exhaustion of the bulb. The gradual preponderance of thermionic conduction over ionic conduction has been gradually increasing as the art has progrest with improvements in pumps, knowledge of the fine points of exhaustion, etc. Thus it has always been impossible to lay a finger upon a certain date or upon any audion type of device, and say, "This marks the distinction between an ionic, or gaseous detector, and a thermionic detector." It is in fact impossible to prove even to-day when audions or oscillions are exhausted to the highest degree that the conductivity is *entirely electronic.*

In the spring and summer of 1906 I had opportunity to spend a good deal of time on the audion problem, and was always seeking to improve its efficiency. Keeping in mind then the disadvantage of directly connecting the high frequency circuit with the local circuits, and harking back to the four electrode gas-flame detector above mentioned, I sought to keep one electrode of the high frequency circuit distinct from the two electrodes of the local current. Obviously the most simple experiment was to *wrap a piece of tinfoil around the outside of the glass bulb and connect this to one end of the secondary transformer of my receiver.* The other end of the transformer was connected to the filament, it being obviously unnecessary to employ four electrodes to effect the end desired. Exactly this arrangement, with the third electrode around the outside of the bulb, is shown in Fig. 3 of patent No. 841,386, which was filed in August, 1906. It will probably be recalled that this outside electrode has been very recently "re-discovered" with considerable eclat and acclaim! I also at this time wrapt a coil of wire around the bulb, connecting one end of this to the antenna and the other to the ground, seeking thus to effect the ionic conductivity between the inner electrodes by electro-magnetic influence from the high frequency oscillations passing around this helix. See Fig. 4, patent No. 841,386.

The arrangement of the external tinfoil belt may therefore be called the *parent of the third electrode.* It showed a decided improvement in the sensitiveness of the detector, as I had anticipated. I recognized that by this arrangement I had in effect a condenser between the filament connection and a hypothetical third electrode, which consisted of the conducting layer of gas located on the interior walls of the bulb, the other arm of this condenser being the tinfoil belt outside the glass. I recognized also that this was a very inefficient and indirect way of impressing the effect of the high frequency oscillations upon the conducting medium between the filament and plate. The third electrode should therefore be placed inside the bulb. I immediately instructed McCandless & Company to make such a bulb. The first type of this third electrode was in the form of a plate, located on the opposite side of the filament from the "B" battery plate. This arrangement showed the increased efficiency and sensitiveness anticipated. It is shown in Figs. 2 and 4 of patent No. 841,387, filed October, 1906. This is the audion amplifier and telephone relay patent. Fig. 2 of this patent is interesting as showing also for the first time a third battery ("B") in the external circuit between the third electrode and the filament. T in this figure represents the high frequency transformer.

In Fig. 4, where this battery is omitted, is shown for the first time the grid stopping condenser C. In studying this type of three electrode bulb, I recognized that the third electrode was not yet in its most efficient position. It should be placed directly in the path of the ionic or thermionic stream, passing from filament to plate, where the high frequency electric charges imprest on the electrode could best affect this stream. But if placed directly between two electrodes, a solid plate, of course, would constitute practically a complete barrier. Hence I devised the *grid* or *perforated screen structure.* In fact, the first audion where the third electrode was placed between the filament and plate utilized the wire bent in grid form which is familiar to every amateur or user of the audion prior to 1914.

This type of third electrode so located was so marked an improvement over the preceding three-electrode bulb, that shortly thereafter a patent was applied for on it. This was issued in February, 1908, No. 879,532. See Fig. 1 where the complete receiving arrangement and the grid audion is clearly shown.

The audion remained in this form for six years. During that time its merits became gradually recognized in Europe as well as here, and it was not long before the little stranger was, like its predecessor, the two electrode brother with "B" battery, adopted into the Marconi family, and like its predecessor re-christened the "Fleming Valve." As soon as the audion amplifier had been developed for long distance telephone service by the engineers of the Western Electric Company, and installed on most of the long distance lines of the A. T. & T. Co., we find certain English publications adopting it also into the Fleming valve family; and now after the three-electrode device has demonstrated its utility as a radio transmitter of absolutely constant undamped waves and made possible transoceanic telephony, we learn that this big brother which I first named the Oscillion, is also the Fleming valve. Not even "junior" or "senior" is used to distinguish one from the other in this rapidly growing Fleming valve family.

The art founded on the three-electrode audion has grown of late years with enormous strides. The great war has produced a tremendous intensity of development for various military purposes and it cannot be disputed that the engineers of the Western Electric Company have taken a foremost position, and much of the present-day efficiency of the detector and amplifier has been due to their efforts, spurred on as they were by the difficult demands and specifications of our Signal Corps officers and engineers. It is estimated that there has been constructed for the U. S. Signal Corps during the war between 200,000 and 300,000 audion and amplifier bulbs, and at least 50,000 small oscillators. In Great Britain wartime production has probably equaled or exceeded the above; while in France we are informed that during the last two years of the war, the audion production has averaged about *5,000 per day!* The French bulb is particularly interesting as being efficient and suitable in all three uses, detector, amplifier and oscillator. For such purposes, of course, a compromise in efficiency was inevitable, and maximum efficiency in either of these three branches has been somewhat sacrificed.

Considerable discussion has lately arisen as to the first use of the audion as an oscillator or source of alternating current. This matter is now being thrashed out in a multiple interference procedure in the U. S. Patent Office. But the evidence so far indicates that the writer's application of this property of the audion in the spring of 1912, marked the first use of the audion as a generator of undamped electrical currents. In view of recent developments, particularly the highly interesting announcements of President Vail of the A. T. & T. Co., regarding multiplex wire telephony and telegraphy over a single conductor pair, it may be prophesied that the application of the audion as a generator of alternating currents will be fully as useful as that of detector and amplifier.

There is, in the writer's opinion, no doubt but that if the development of radio is not now made a Government monopoly, it will not be long before commercial trans-oceanic wireless telephony will be effected. This work, whether the generator be a bank of oscillions or a high frequency alternator, will be made possible only thru the extraordinary amplifying properties of the audion, when used as telephone repeater or relay.

The simplicity of the oscillion transmitter in small sizes, coupled with the extraordinary sensitiveness of the "zero beat" audion detector or amplifier of received high frequency energy, warrants the belief

(*Continued on page* 831)

mented tissue, which reflects the light outward. An opaque tissue situated just behind the reflector prevents the light from entering the body.

Lenses, which are often present, tend to concentrate and throw the light forward. These lenses consist of a transparent cartilage covered with a transparent skin. In addition some fish even have *shutters* with which they can turn off their light at will.

Many deep sea fish have in addition to their principal organ of light many minor ones, which give the surrounding waters an iridescent glow. As the fish swim along these many varicolored scintillating lights give off a phosphorescent effect. These flickering will-o'-the-wisps of the deep are chased by openmouthed terrors that follow a searchlight at the tip of their own nose.

The lights with all their many shades of color, patterns, and places of attachment are primarily used for the identification of the species and the sexes. They are of secondary importance in the aid they give for the search of food, in which case they are undoubtedly used to attract, dazzle, and entrap its prey. Oh! yes. They are some little *Vampires* all by themselves.

But in order to see the phosphorescent glimmer of a fish at a distance, the eyes have been peculiarly modified. The greatest possible number of rays of light given off by a point are absorbed by the eye, and this is effected by either enlarging the eye as a whole or by enlarging only the lens and removing the retina to a distance. In this way the eyes have become cylindrical.

It is not the deep sea fish alone that possess organs of light. Some varieties of fish inhabiting the well lighted part of the ocean have them as well. These, which are commonly called "lantern fish," emit, at rhythmic intervals, a greenish-white light. A shutter, which is an opaque membrane similar to that found on a camera, is pushed or pulled over the light organ. This effectually conceals the rays. Two small varieties comprising the Anomalopidae inhabit the Malay archipelago at the Sunda islands, while a third variety has recently been discovered near Jamaica.

Our front cover shows three very interesting species of deep sea fish. The fish illustrated at the top is *Gigantura chuni, A Br.* The fish in the center with the peculiar elongated nose-piece is *Gigantactis vanhoeffeni, A. Br.* While the bottom fish is *Stylophthalmus pardoxus, A. Br.*

These are not very large fish, as one might think, and the illustrations on our front cover are about half size. In other words, the fish are only about twice as large as shown on our cover. The fish illustrated at the top is also slightly luminous around its body, as can be seen. One of the most curious of these fish without doubt is the middle fish. Why Nature should have equipt it with such a long nose-piece, the end of which is luminous, is not well understood as yet, as we know very little about these fish. The interesting part about the lower fish is that it has luminous organs all along its sides, while the eyes themselves are but slightly luminous. It is curious that the eyes themselves are not in sockets as is usually found the case with nearly all other animals, but that they extend several inches from the head.

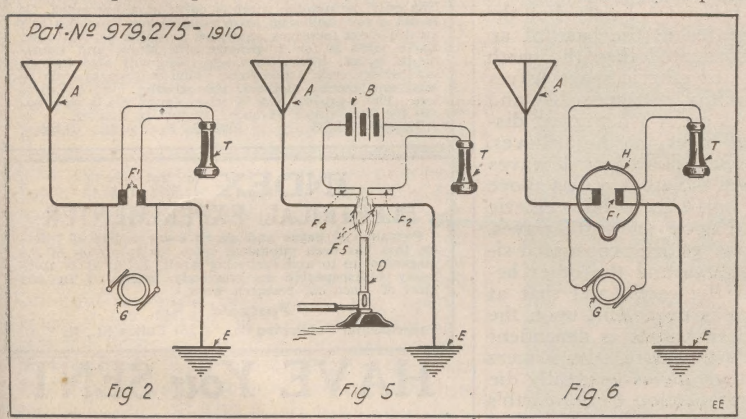
[*Editor's Note*: *The curious deep sea fish shown on our front cover were prepared from color drawings made by Dr. Bade himself. He in turn worked from the actual fish brought from the deep when making his drawings.*]

HOW I INVENTED THE AUDION.

(*Continued from page* 820)

that before long the wireless telephone will be installed on thousands of vessels, supplementing, and in many cases, supplanting the wireless telegraph. In addition there is an enormous number of small vessels where a wireless telephone installation is more feasible.

As indicative of the growth of the Audion Art, the number of patents issued on various devices and circuits dependent thereon, gives a pretty fair key: Up to 1912 there had been issued about 20 patents, all filed subsequent to 1904. To-day there are over 100 United States patents on the Audion Art, and the number is very rapidly growing. Regardless of what name may be applied to the device patented, practically everyone of these patents since 1906 shows the three electrode bulb. They may all therefore be properly described as the outgrowth of the ideas first shown in the audion amplifier—patent No. 841,387.



Altho This Patent Bears the Date of 1910, It Was Originally Filed in 1904, and Is One of the Basic Patents in All Audion Development. It Shows the First Use of Incandescent Filaments in an Enclosed Chamber, and, Moreover, It Includes at Fig. 5 the First Evidence of the Third Electrode or "Grid" Conception. Here, as Will Be Evident, Is the First Plan for Separating the Antenna Circuit from the Local Circuit.

EXPERIMENTAL CHEMISTRY.

(*Continued from page* 794)

euprous oxid, or gold; *Yellowish-green,* by uranium oxid; *Green,* by chromic or cupric oxids; *Milk or Opal* glass is made by the addition of bone-ash, tin or zinc oxids. The green color of the common window glass or bottle glass is caused by the presence of ferrous oxid in the sand; this discoloration may be removed by addition of manganese dioxid in the make-up. This serves to oxidize the ferrous to ferric oxid, which imparts a yellow tint, being neutralized by the violet produced by the manganese as a complimentary color.

Pure white sand is mixed with the metallic oxids required, in the proportion which experience has shown gives the best results, and some old glass, called "cullet", is added to improve the quality. The mixture is then put into pots as shown in Fig. 159. These pots are made of the most refractory fire-clay, and are placed in a circular furnace with openings thru which the workman can dip his long iron blowpipe into the pots. Fig. 160 shows such a furnace in cross-section.

The fuel now used is mostly gaseous, and an intense heat is maintained for hours, till the substances are completely fused and mixed. The glassworker dips his blowpipe—a hollow iron rod 5 or 6 feet long, into the fused mass, removes a small portion, rolls it on a smooth iron